

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)



ABSTRACT

The In-Space Manufacturing (ISM) project is responsible for developing the manufacturing capabilities that will provide on-demand, sustainable operations during NASA Exploration Missions (in-transit and on-surface). This includes testing & advancing the desired technologies, as well as establishing the required skills & processes for the processes (such as certification and characterization) that will enable the technologies to become institutionalized.

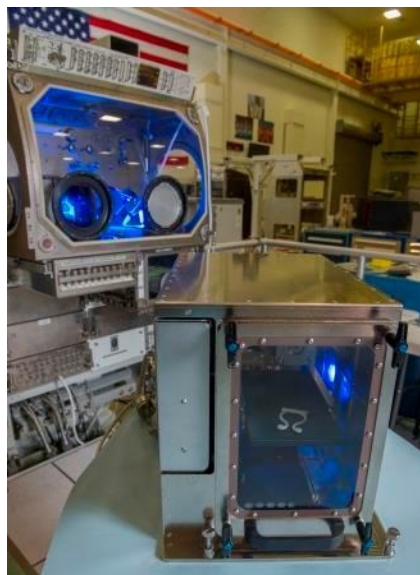
The key capabilities being developed in ISM to support this “make it, don’t take it” approach include developing a 3D printing Fabrication Laboratory (‘FabLab’) that can manufacture parts in space using multiple materials, as well as the ability to embed printed electronics, in-space recycling of printed parts and other materials such as packaging in order to reduce mass and waste, and manufacturing structures externally in space. In 2015, the ISM project made history by sending the first 3D printer to ISS and manufacturing the first parts ever in space. This was a critical first step in demonstrating additive manufacturing in microgravity.

Note: Prior to FY15, this project was named the Additive Manufacturing Technology Development project.

ANTICIPATED BENEFITS

To NASA funded missions:

The capability to produce hardware on-demand, using 3D printing technologies, will directly lower cost and decrease risk by having the exact part or tool needed in the time it takes to print. This project is the first step towards realizing a “machine shop” in space that is a critical enabling component of any Deep Space Exploration Mission. Successful development of a material recycler will allow deep-space missions to reuse existing material and require less original feedstock for printed



3D Printing in Space Test on the International Space Station (ISS)

Table of Contents

Abstract	1
Anticipated Benefits	1
Technology Maturity	2
Realized Benefits	2
Management Team	2
Technology Areas	3
Detailed Description	4
U.S. Work Locations and Key Partners	6
Latest Success Story	7
Details for Technology 1	7

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)



parts. Customers for ISM include NASA deep space missions (Human Exploration and Operations Mission Directorate), specifically the Advanced Exploration Systems Division, the Space Technology Mission Directorate's Game Changing Development Program, and the ISS Program.

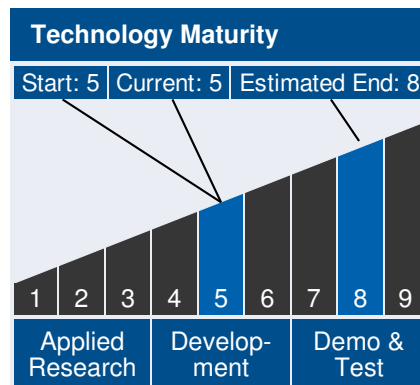
There are many savings associated with having an additive manufacturing device available during a mission:

1. Reduced up-mass and volume for spare parts resulting in fewer launches (i.e., decreased cost and schedule to achieve exploration missions).
2. Does not require fabrication, launch, and flight time from Earth for delivery.
3. Production time can be on the order of minutes or hours.
4. Ability to print parts and/or architectures never conceived due to the unique attributes of additive manufacturing and not having to design around launch load constraints.

To NASA unfunded & planned missions:

Customers for ISM include NASA deep space missions (Human Exploration and Operations Mission Directorate) specifically the Advanced Exploration Systems Division, the Space Technology Mission Directorate's Game Changing Development Program, and the ISS Program. There are many savings associated with having an additive manufacturing device available during a mission.

1. Reduced up-mass and volume for spare parts resulting in fewer launches (i.e., decreased cost and schedule to achieve exploration missions).
2. Does not require fabrication, launch, and flight time from Earth for delivery.
3. Production time can be on the order of minutes or hours.
4. Ability to print parts never before conceived to build



Management Team

Program Director:

- Jason Crusan

Program Executive:

- Douglas Craig

Project Manager:

- Mary Werkheiser

Principal Investigator:

- Mary Werkheiser

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development)

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)



structures, handle mission critical situations, etc.

To other government agencies:

FY15/16 : Defense Advanced Research Projects Agency (DARPA): The ISM project and Defense Advanced Research Projects Agency (DARPA) are working together to identify technologies that can be utilized for on-demand, external, in space manufacturing and repair. The Air Force is interested in the ability to manufacture small CubeSats in-space, on-demand. The Army and Navy are interested in leveraging the lessons learned for creating high performance, small, safe, on-demand manufacturing facilities for undersea and on-land soldier deployment applications.

To the commercial space industry:

The terrestrial commercial market for these technologies is disruptive and evolving quickly. The NASA ISM project utilizes mechanisms such as Small Business Innovation Research (SBIR) awards, Broad Agency Announcements (BAA), Challenges, etc., to work closely with industry in order to leverage these rapid technology advances. This results in stimulating the terrestrial economy in this area, while utilizing the limited NASA resources to focus on adapting these technologies for microgravity applications. Additionally, ISM helped to establish and will be the first government user of the commercial printer that Made in Space, Inc. is launching to ISS thru CASIS.

To the nation:

Manufacturing advancements have been encouraged by Presidential Executive Order 13329, which requires a high priority, be given to advanced manufacturing-related research. ISM introduced two new SBIR topics relative to recycling in space and awarded five SBIR contracts to commercial companies. Additionally, the ISM project initiated a Space Act Agreement with the American Society of Mechanical Engineers (ASME) for the Future Engineers national Science, Technology, Engineering and Mathematics (STEM) program, which provides

Technology Areas

Primary Technology Area:

Ground and Launch Systems (TA 13)

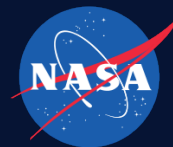
└ Operational Life-Cycle (TA 13.1)

└ Logistics (TA 13.1.4)

└ Additive Manufacturing as Replacement for Original Equipment Manufacturer (OEM) Spare Parts (TA 13.1.4.3)

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development)

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)



K-12 challenges to students for ISM print designs. This is aiding in arming our nation's children with a meaningful design skillset that will ultimately help to restore manufacturing capabilities in the U.S.

The ISM project provides unique benefits to the nation. The ISM project will add a level of compactness and efficiency that will enable additive manufacturing in remote and economically suppressed regions of the world that don't currently have the resources to use this technology. The ISM project will validate additive manufacturing in unique and harsh environments, potentially enabling additive manufacturing to be used in unique and harsh terrestrial environments where it is not currently available. People in harsh environments like the desert, or very cold environments would be able to utilize additive manufacturing to develop customized parts on demand, customize healthcare products, reduce environmental impacts for manufacturing sustainability, and simplify the supply chain to increase efficiency and responsiveness. These technologies can improve the quality of life.

Furthermore, the public and education outreach interest in this project has been overwhelming. More than 1,100 publications were published in such media as Yahoo News, Huffington Post, Fortune Magazine, Wall Street Journal, CBS, CNET, MSNBC, Popular Science, and space.com.

DETAILED DESCRIPTION

Long-term mission objectives require a dramatic paradigm shift in the design and development of space architectures. An analysis of the Problem Reporting and Corrective Action System for failures on the ISS revealed that 88% of those failures could have been remedied and hardware put quickly back into operation with on-board fabrication and repair technologies. ISM offers an elegant solution for sustainability and affordability by identifying and developing on-demand processes, such as additive manufacturing, to address the in-space construction, repair, and maintenance of vehicles, critical systems, habitats, and uncrewed spacecraft for long-duration missions (both in-transit and on-surface). These capabilities, along with the optimum use of recycled and in situ materials, provide meaningful mission cost savings due to reducing launch mass, as well as significant risk reduction due to decreasing dependence on spares and/or over-designing systems for reliability. Objectives will be met through the demonstration of periodic, evolving technology demonstrations in space environments.

To truly develop the capabilities needed for the first long-duration exploration missions, ISM is generating the requirements for an integrated multi-material Fabrication Laboratory ('Fab Lab') that will be capable of manufacturing multi-material parts with embedded electronics, autonomous operations, inspection capability, and optimized performance for volume, accuracy, repeatability, etc. The first generation Fab Lab will be a rack facility on the ISS competed via a Broad Agency

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development)

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)

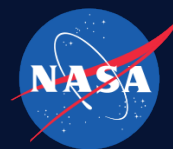


Announcement (BAA) in 2017. Near-term objectives that inform the requirement development include continued operations of the 3D Printer Tech Demo (Small Business Innovation and Research (SBIR)) onboard the ISS, use of a commercial Additive Manufacturing Facility (AMF) printer (also SBIR and CASIS) scheduled to be delivered to the ISS in FY16, and the characterization of ground and space-printed parts to determine microgravity effects, if any. Other FY16 work includes the development of an in-space recycler demonstration for the ISS in FY17 (via SBIR) and multiple SBIRs to identify and evaluate common-use materials that can initially serve as packaging and stowage materials, then be recycled into raw feedstock for the additive manufacturing of new parts.

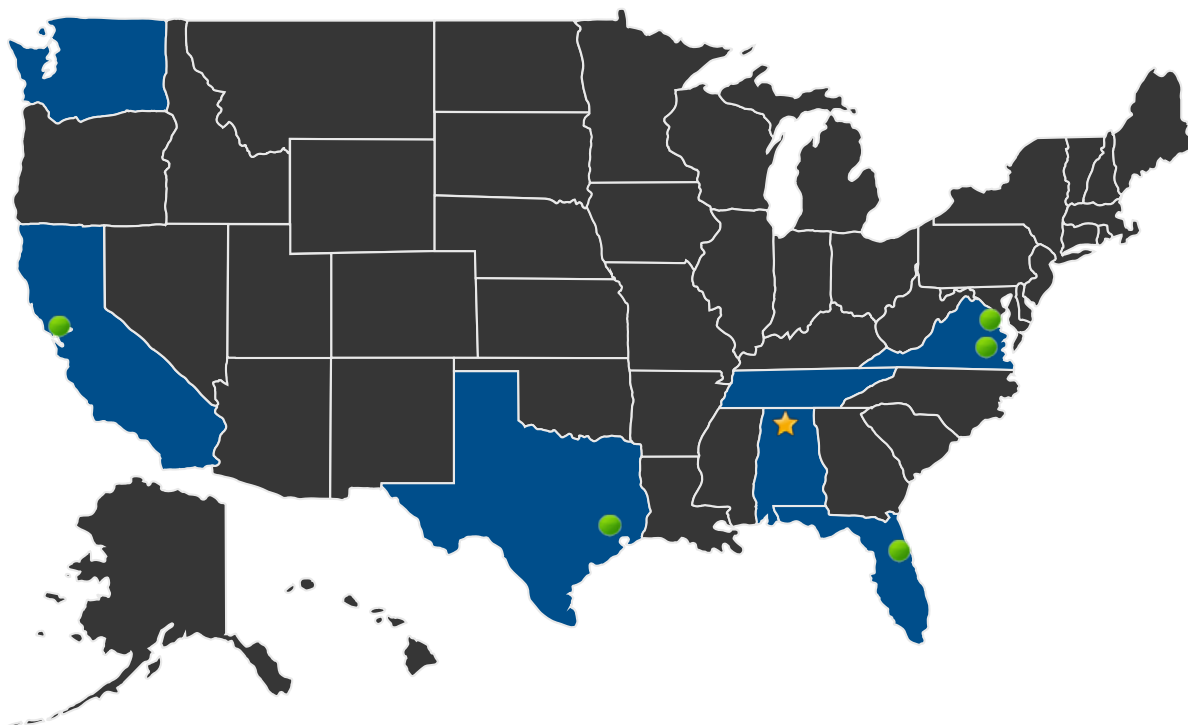
These new 3-D printing technologies will provide the capability to produce hardware on-demand, directly lowering costs and decreasing risk by having the exact part or tool needed in the time it takes to print. This capability will also provide the much-needed solution to the cost, volume, and up-mass constraints that prohibit launching everything needed for long-duration or long-distance missions from Earth, including spare parts and replacement systems. This project is the first step towards realizing a “machine shop” in space, which is a critical enabling component of any deep space exploration mission.

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development)

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)



U.S. WORK LOCATIONS AND KEY PARTNERS



■ U.S. States With Work

★ **Lead Center:**
Marshall Space Flight Center

● **Supporting Centers:**

- Ames Research Center
- Johnson Space Center
- Kennedy Space Center
- Langley Research Center
- NASA Headquarters

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development)

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)



Other Organizations Performing Work:

- Cornerstone Research Group, Inc. (Dayton, OH)
- Made in Space, Inc. (Wilmington, DE)
- Techshot, Inc. (Greenville, IN)
- Tethers Unlimited Inc
- University of Puerto Rico
- Vanderbilt University (Nashville, TN)

Contributing Partners:

- Defense Advanced Research Projects Agency (DARPA)

LATEST SUCCESS STORY

3D Printing on the International Space Station: A Key Step to Pioneering Sustainable Exploration Missions

PROJECT LIBRARY

NASA Technology Use

- Launched the first 3D Printer in space on SpaceX-4 Cargo Mission to ISS on 9/21/14

Success Stories

- 3D Printing on the International Space Station: A Key Step to Pioneering Sustainable Exploration Missions
 - (<http://techport.nasa.gov:80/file/18368>)

DETAILS FOR TECHNOLOGY 1

Technology Title

In-Space Manufacturing

Technology Description

This technology is categorized as a hardware system for manned spaceflight

ISM objectives are to provide:

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development)

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)



1. Detailed understanding of the critical design and operational parameters for the additive manufacturing process as affected by the microgravity environment
2. The first demonstration of additive manufacturing in space
3. A detailed analysis of how acrylonitrile butadiene styrene (ABS) thermoplastic resin behaves in microgravity versus Earth's gravity
4. A comparison between additive manufacturing in Earth's gravity with consistent, long-term exposure to microgravity (insufficient in parabolic flights due to "print-pause" style of printing)
5. Advance the TRL of additive manufacturing processes to provide risk reduction and capabilities to future flight or mission development programs

The ISM project is responsible for developing the manufacturing capabilities that will provide on-demand, sustainable operations during NASA exploration missions (in-transit and on-surface). This includes testing & advancing the desired technologies, as well as establishing the required skills & processes (such as certification and characterization) that will enable the technologies to become institutionalized. Examples of the technologies under development for in-space applications include 3D printing with multiple materials including plastics, metals, and electronics, recycling of printed parts and packaging materials to generate reusable feedstock, and autonomous and remote capabilities.

These technologies are evolving quickly. The ISM project leverages industry, academia, & other govt. organizations to meet these objectives.

The ISM project utilizes ground-based and ISS demonstrations as the proving ground for the evolution of these capabilities from Earth-reliant to Earth-independent.

Capabilities Provided

The ISM project will demonstrate the capability of utilizing additive manufacturing technology in space. This is the first step towards realizing an additive manufacturing, print-on-demand "machine shop" for long-duration missions and sustaining human exploration of other planets, where there is extremely limited ability and availability of Earth-based logistics support.

Potential Applications

This is the first step towards realizing an additive manufacturing, print-on-demand "machine shop" for long-duration missions and sustaining human exploration of other planets, where there is

In-Space Manufacturing Project (prior to FY15: Additive Manufacturing Technology Development)

Advanced Exploration Systems Program | Human Exploration And Operations Mission Directorate (HEOMD)



extremely limited ability and availability of Earth-based logistics support.

The application from this technology demonstration will be used for the next generation of melt deposition modeling in the permanent NanoRacks Additive Manufacturing (AMF) as well as for any future additive manufacturing technology NASA plans to use, such as metals or electronics in-space manufacturing, on both the ISS and deep-space missions.

Other application for 3D printing can spur new technologies such as: the need for recycling additively manufactured parts back into feedstock to use in the printer multiple times to construct multiple parts, printing of electronics in space, printing of CubeSats, which could be printed and assembled on orbit without structural constraints determined by launch loads and systems that could be designed with parts that could be changed out or compatible with additive manufactured parts produced on orbit.

Other applications include the potential for refining additive manufacturing technology for use on Earth. Current additive manufacturing technologies are used in the medical field for expertly crafted replacement structures, making jewelry and toys, and other currently evolving platforms. These technologies will improve the quality of life.